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ABSTRACT

The topic of metals is frequently taught in primary schools. However, when metals are suggested as one of a series of topics for study, students often initially show little enthusiasm for the topic. To determine the ideas that children have about metals the Learning in Science Project (Primary)--LISP(P)--interviewed thirty-eight 9- to 10-year-old children. Each child was presented with a range of metallic and non-metallic objects and asked to put them into metal or non-metal groups, and to give their reasons for each categorization. Results indicate a wide range of reasons why objects were considered to be made of metals. They are discussed under these headings: heaviness; shiny or silvery color; hardness or strength; magnetic quality; texture and temperature; and intuitive knowledge. Additional data were obtained by analyzing 211 questions about metals provided by students in nine classes. These questions focused on the identification, range/nature, properties, uses, origin/location, and manufacturing, of metals. Overall results clearly show that most students have a restricted concept of a metal, exemplified by a large heavy piece of steel; heavy, silvery in color, magnetic, and hard, typifies a metal object to most children. Implications of this conclusion for science instruction are briefly addressed. (JN)

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# LEARNING IN SCIENCE PROJECT (PRIMARY)

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# CHILDREN'S IDEAS ABOUT 'METALS'

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SE 015 314



Working Paper No. 112

# CHILDREN'S IDEAS ABOUT METALS

Fred Biddulph and Roger Osborne

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A working paper of the Learning in Science Project (Primary)

No. 112

## THE TOPIC OF METALS

Metals play an important part in all our lives. The ability of common metals to conduct heat (e.g. kitchen pots), to conduct electricity (e.g. copper wires), to provide strength (e.g. concrete reinforcement rods), to be shaped and moulded (e.g. steel wires, engine blocks) and to be produced in thin sheets (e.g. roofing, car bodies) means that metals have many and varied uses in our modern technological society. Metals are also of interest in terms of how they are affected by air and water (e.g. rusting of cars), how they can be used in solutions (e.g. electro plating), and how some of them can be used for magnets (e.g. iron).

For reasons such as the above, the topic metals would appear to have considerable value in both primary and secondary science education. According to Primary Science Advisers the topic is one that is frequently taught at the S3-4 (9-11 year old) level. On the other hand, when it is suggested as one of a series of topics they might study, it is not a topic children initially show much enthusiasm for (Biddulph, Osborne and Freyberg 1983). Also the scientific reasons as to why some substances are called metals, and others are not, are impossible to fully appreciate without a senior chemistry student's understanding of atomic structure. However, we should not necessarily be led into a view that because of these factors pupils' current ideas on this topic cannot be usefully challenged. To explore this further we need to gain some appreciation of children's present ideas on this topic.

## CHILDREN'S IDEAS ABOUT METAL

Thirty-eight 9-10 year old children from two mixed ability standard 3 classes were interviewed individually. Each child was presented with a range of metallic and non-metallic objects. These included a stainless steel knife, magnet, lead sinker, aluminium milk bottle top, ceramic tile, 2¢ coin, toothpaste tube, rock, nail, steelo pad, copper pipe, drawing pin, plastic frypan foot, stainless steel brake cable and a mirror. Each child was asked to physically place those objects that they considered to be made of metal in one group and those that were not made of metal in another. They were asked for their reasons for each categorisation, and self-contradictory reasons and unusual explanations were investigated further.

## TWO MEANINGS FOR THE WORD 'METAL'

The N.Z. Dictionary gives two meanings for the word metal.

(i) Chemistry: any of those elements which tend to be ductile and malleable, conduct heat and electricity and form positive ions.

(ii) road 'metal', stone chips.

A small piece of rock, which might come from an unsealed road, was included in the objects to be classified. However, only 3 of the 38 children considered it to be metal and two were not sure. To the vast majority of pupils the piece of rock was not metal; it was 'rock' or a 'stone'. This finding suggests that children are unlikely to be influenced in a study of the topic 'metal' by ideas about road metal. On the other hand, children's ideas on this may be geographically dependent. The 38 children interviewed were city children unlikely to have heard about the problems of unsealed roads. Responses from country children continually listening to parents complaining about the Council not having put metal on the roads may be quite different. It is certainly a potential confusion that is worth discussing with a class.

## WHY AN OBJECT IS CONSIDERED TO BE MADE OF METAL?

Children gave a range of reasons why objects were considered to be made of metal.

Heaviness: A common reason why an object was considered to be a metal was "heaviness". In most cases this referred to heaviness for its size, e.g.

> [the copper pipe] "It is a metal because it is a bit heavy."
>
> [the lead sinker] "It's metal because it's heavy. Metals are heavy."
>
> [the magnet] "It is metal because it is quite heavy like the [lead sinker] anchor ."

As an example of the prevalence of this reason, 92% of pupils considered the stainless steel knife to be made of metal and of these pupils, over 30% of them gave 'heaviness' as the reason.

Where the term 'heaviness' did not refer to some appreciation of density but referred more to absolute weight this reason led to problems. Two children stated that the 2¢ coin was not metal as it was not heavy enough. Similar reasons were given by three children with respect to the milk bottle top.

Undoubtedly it is useful for pupils to appreciate that most common metals are heavy for their size, but they also need to appreciate that a very small amount of a metal will still appear very light. This has relevance to ideas about floating and sinking, for example.

Shiny or Silvery Colour: This was also a commonly given reason as to why objects are regarded as metal. For example, four of the 34 pupils who said the rusty nail was metal stated, "because it would be silver if it wasn't rusty".

Forty percent of the children who considered the stainless steel knife to be made of metal gave a reason related to appearance.

Many common metals do have a characteristic shiny or silvery colouring if they are polished or scraped to remove the oxidation layer, e.g. rust or tarnish. This characteristic colour is associated with the fact that metal is a good conductor of electricity. However, it is possible to obtain a metallic-like look in other ways, as anyone who has looked at multi-layers of overhead projector transparencies, or fish scales will know.

Hardness or strength: Hardness or strength was another common reason why an object was considered to be a metal.

"The nail is metal because it's very hard, hard to bend."

[2¢ coin] "It's metal. I think money is made of metal because it's mighty hard. It's hard to break it."

[lead sinker] "It is metal. It's hard and tough."

On the other hand, 55% of the children interviewed rejected the aluminium milk bottle top as metal because it could be bent or squeezed. Forty percent of the children rejected the metal steelo pads from the group of metals because it was "bouncy", "all woolly", "furry with spaces", "soft and spongy", "squashy", "fluffy", and "carpety".

Undoubtedly many common metals are relatively hard but this is not a useful criterion by which to distinguish metals from non-metals. Diamond, glass, certain rocks, are all examples of hard non-metallic substances. Not only are milk bottle tops and steel wool relatively 'soft' but so are metals such as lead, lithium and mercury!

Magnetic quality: Whether or not an object was attracted to a magnet was used by some children to determine which objects were metal and which were not.

[the nail] "Yes, it's metal. I've tried it before. It sticks on to a magnet."

[aluminium bottle top] "This is not metal because it would just fall off a magnet."

In the course of the interviews 40% of the pupils stated that metal things can be picked up by, or will stick to, magnets.

While some metals are magnetic, (e.g. iron), other metals, (e.g. copper, aluminium) are not magnetic in any significant way. For this reason it certainly cannot be argued that if a substance is non-magnetic then it is not a metal.

Texture and Temperature: Occasionally the smoothness of an object or the fact that it appeared cold to touch was used to argue that a particular object was or was not a metal.

[the pocket knife] "It's metal. It feels like metal. [How do you mean?] It's smooth."

"The pipe is metal. It's cold; plastic doesn't feel like that."

Metals often appear cold to touch because they conduct heat easily. Hence if the metal is below body temperature heat is conducted away relatively fast from the finger touching it into the metal; the metal appears cold. Of course if the metal is above body temperature it will be hot to touch. Hence, on its own, "cold to touch" is not a sensible criterion to decide whether or not something is a metal.

Intuitive knowledge: Many children at this age are unable to suggest any perceived attributes of metals as reasons for their categorisation of the items. Many of these children may simply have heard, or read, that nails, magnets, and so on are made of metal.

"The 2¢ coin is metal. I've seen on T.V. how they are made out of sheets of metal. All this kind of money is made out of metal."

[the steelo pad] "It's metal. I think sometimes it's called steel wool, and steel is metal".

[the pocket knife] "It is metal. Most pocket knives are metal. Dad has one and he said it is made of metal."

One of the problems of this tacit knowledge is that if they learn later, for example, that knives are made of stainless steel and nails are made of steel, they can become unsure of the status of their earlier ideas. To illustrate, two of the three children who did not consider the knife to be a metal stated that their reason was that it was made of steel; to two children a piece of pipe was not a metal as it was made of copper; to others the sinker was not a metal because it was made of lead. Other examples include:

[Magnet] "It's not metal because it's a magnet.

[Cable] "It's wire, not metal."

Invariably it was an assumed incompatibility of categorisation, rather than lack of suitable attributes, which was used by pupils as a 'reason' why the non-metallic objects were not metal.

[Rock] "It's definitely rock, not metal."

[Tile] "No, it's not metal; its china."

[Fry pan foot] "It's plastic. Legs of pans are usually just plastic, not metal."

In part, this problem is associated with a lack of an appreciation of the hierarchical nature of some concepts, such as copper, steel, aluminium versus metal, and appears to be a parallel conceptual problem to the insect, reptile, mammal versus animal problem we have discussed elsewhere.

Number of children responding to "Is it made of metal"

| | Yes | No | Partly | Not sure |
|---|---|---|---|---|
| 1. Stainless steel knife | 35 | 2 | - | - |
| 2. Bent rusty nail | 34 | 1 | - | - |
| 3. Magnet | 31 | 1 | 2 | 4 |
| 4. Copper pipe | 31 | 4 | - | 3 |
| 5. Lead sinker | 26 | 11 | - | 1 |
| 6. Drawing pin | 24 | 7 | - | 7 |
| 7. 2¢ coin | 20 | 14 | - | 4 |
| 8. Brake cable | 18 | 12 | 2 | 6 |
| 9. Metal bottle top | 17 | 11 | 1 | 9 |
| 10. Toothpaste tube | 12 | 14 | 3 | 9 |
| 11. Steelo pad | 11 | 16 | 2 | 9 |
| 12. Milk bottle top (aluminium) | 5 | 26 | 3 | 4 |
| 13. Mirror | 3 | 30 | - | 5 |
| 14. Rock fragment | 3 | 33 | - | 2 |
| 15. Plastic frypan foot | 1 | 32 | - | 5 |
| 16. Ceramic tile | 1 | 36 | - | 1 |

Table I: 38 children's responses to the instances and non-instances of metal.

Summary: Table I gives the breakdown of the number of pupils who classified each object to be a metal or not. Where metal objects were heavy, metallic in colour, and hard, then these objects were classified as a metal usually for one of these reasons. Where an object was magnetic this was also a reason used for it being a metal.

It is impossible for primary children to begin to appreciate the scientists' concept of a metal as this is firmly embedded in an appreciation of the periodic table. Nevertheless, children at that age have ideas about metal characteristics, many of which could be usefully challenged. For example, children can begin to appreciate that the characteristics of being hard, heavy, magnetic, cold to touch and/or metallic in colour are not always useful attributes for deciding if something is a metal or not; the characteristics of the most common metal, steel, (hard, strong and magnetic) are not the chacteristics of all metals.

> "When we think of a metal, we are almost sure to think of something hard and heavy. But there are metals that are neither hard nor heavy. Some of them are so light they will float on water, and some are so soft, as to flow around like oil.
>
> [Richards Topical Encyclopedia, Vol.9, p.417, 1947.]

To learn of lithium (lighter than water) and mercury (softer than oil) is something of interest to some children. Perhaps out of a discussion of steelo pads, and other challenges to their ideas of metals, there will be some children who will usefully seek out a list of metals, their properties, and their uses as a project. The rarity of many metals and hence lack of opportunity for pupils to observe and feel them, the lack of opportunity to relate many of the metals to everyday life, the impossibility of explaining the defining attributes of the scientists' concept of metals to young children, all argue toward the view that the names and properties of metals are at best topics for only a few interested individuals or groups of primary school children.

CHILDREN'S QUESTIONS ON METALS

The confirmation that the identification of metals is not of great relevance in primary schools comes from an investigation of what questions pupils have about metals. 211 questions were obtained from children in nine S2-4 classes, (1 xS.2, 3 x S.3, 1xS.3-4, 4 x S.4) using the methods and stimuli described in Appendix 2. Of these questions less than 10% relate to the identification of metals. Questions like

"How can we tell if objects are really metal?"
"What is metal?"

are questions that are asked infrequently.

Another 12% of questions relate to the range and nature of metals. Questions such as

"How many different kinds of metals are there?" and
"Is there any heavier metal than lead?"

are topics that could more usefully be explored as a library project, as we suggested earlier. Perhaps we need to keep in mind that the pupils with an interest in this type of systematisation of knowledge could well be our future scientists. It is certainly something scientists like to do.

Solomon (1980) argues that, unlike scientists who are interested in documenting the common properties and regularities in nature, many children are interested in the special and the unique. Some 20% of pupils' questions related to special properties of metals.

"Why is aluminium light?"
"Why do magnets hook onto metal and not anything else?"
"Why are some metals light and some are heavy?"
"How do different metals have different colours?"

These are all questions for which there are not satisfactory answers for children of this age, nor in many cases do scientists have entirely satisfactory answers for themselves!

Other questions which are not "why" questions can be more satisfactorily answered,

"What temperature do certain metals melt at?"
"Do all metals rust?"

A popular set of questions related to uses of metals. Some 20% of questions were of the type,

"Are many boats made from metal?"
"What were the first uses of metal?"
"What are metals mostly used for?"

These are "applied" science or "consumer" science type questions which have answers which may be researchable by children through suitable resource books if they are available.

Ten percent of questions were concerned with the origin, composition and location of metals. Questions included,

"Where does metal come from?"
"How is metal located?"
"Who discovered/invented metal?"

The remaining 20% of questions were concerned with the manufacturing of metal objects, for example,

"How do they make it so flat, like foil?"
"How do they get it so soft so they can mould it into things?"
"How do they get the pattern onto 2p pieces?"

A subset of this final set of questions suggests, as did the earlier interview work, that some pupils considered metal primarily in terms of

steel/iron or at least considered that metals were manufactured rather than mined.

"How is metal made?" and
"What is metal made out of?"

were two of the most common questions asked and were offered in 70% of the classrooms where questions were sought. When asked for a possible answer, many pupils appeared to have an image of cooking up various ingredients as in making glass.

"I think you have sand in it and some other things, then heat it."

To this was added the idea that the mixture was "boiled to make it hard" or "left to dry".

Enquiries about where these ideas came from suggested that they tended to come from television, family members, or were constructed from the children's experiences (first hand or vicarious) by means of analogy.

## SUMMARY AND FINAL CONSIDERATIONS

This study shows clearly that most pupils have a rather restricted concept of a metal, exemplified by a large heavy piece of steel; heavy, silvery in colour, magnetic, and hard, typifies a metal object to most children.

The properties of the common metals which are often used to characterize them, malleable, ductile, and conductors of heat and electricity were not mentioned by a single one of the 38 pupils interviewed.

In many ways, concepts like animal, rock and metal have much in common. They are frequently used terms with meanings in everyday language, but they each have sophisticated well-defined meanings in science which are subtly different from their everyday meanings.

| | Everyday meaning | Scientific meaning based on |
|---|---|---|
| Animal | Furry, four-legged mammals | An appreciation of ecological principals |
| Rock | A jagged, hard, dark lump of material from the earth | An appreciation of minerals |
| Metal | A silvery coloured, hard, heavy material which is probably magnetic | An appreciation of the periodic table or conductivity |

As these scientific meanings are beyond young children, should we introduce simple definitions suitable for children as an introduction to the concept? Should we simply extend or modify their appreciation of exemplars and non-exemplars? Should we ignore concepts such as these which are not developed through hands-on experimentation?

We suspect that, as with the term 'animal' and 'rock', secondary school teachers simply assume that children know what 'metals' are. If pupils are told that a salt is formed by the action of an acid on a metal, then, at best, they may not interpret it in the broad sense that the secondary teachers might expect. At worst, the ideas constructed by many pupils (such as pupils who consider steel wool to be too light to be a metal) may be so different from those intended by the teacher that no meaningful learning can occur.

It could well be argued that it is desirable to extend primary children's ideas of metals and how they are obtained. It could also be argued that this could take the form of a social studies type unit or project. Maybe we have to review what is this thing called primary science in terms of the place of factual information. Pupils do not discover by hands-on experimentation that mercury, gold, brass, bronze, silver, steel, iron, tin, lead, copper, nickel, zinc, and tungsten are metals. When and how

they are told, and what reasons they are given as to why they are metals are questions that remain to be considered.

At the very least it could be argued that to know that milk bottle tops and steel wool are made of aluminium and steel respectively, and that these are both metals, would be new information which would be a challenge to the limited views of young children. Why such things are made of metal, instead of wood or plastic, may well provide even more useful investigation for pupils if resource books or knowledgeable people are available.

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APPENDIX 1

| ITEM | DESCRIPTION |
|---|---|
| 1. knife | stainess steel pocket knife |
| 2. magnet | small horseshoe magnet painted red but with shiny ends |
| 3. sinker | dull lead, pyramid-shaped, typically used on fishing lines |
| 4. milk bottle top | aluminium with blue pattern denoting homogenized milk |
| 5. tile | clay tile approximately 100mm x 100mm with shiny blue glaze |
| 6. 2¢ coin | NZ currency, dull copper colour |
| 7. tooth paste tube | almost empty, squeezed flat, white with silver by screw cap |
| 8. rock | small piece of greywacke, typically found on roadside |
| 9. nail | rusty, partly bent, approximately 80mm long |
| 10. steelo pad | commercial steelo pad, used for cleaning saucepans |
| 11. pipe | piece of copper pipe approximately 30mm long, diameter approximately 20mm, formerly used for hot water plumbing |
| 12. drawing pin | typical brass-coated steel drawing pin |
| 13. fry-pan foot | hard black plastic, from electric fry-pan |
| 14. bottle top | small metal screw top, painted white on outside, plastic seal inside |
| 15. brake cable | piece of bicycle hand-brake stainless steel cable splayed out at one end |
| 16. mirror | small (approximately 80mm x 50mm) glass mirror detached from its usual plastic case. |

APPENDIX 2

HOW CHILDREN'S QUESTIONS WERE OBTAINED

Eighty-seven questions about 'metals' were obtained from children in six S.2-4 classes (one S.2, one S.3/4, Four S.4). These were obtained in special 'lessons' taken by the researcher using the first two steps of the alternative teaching approach proposed by Biddulph and Osborne (1982). The stimuli used were a range of metals (including pieces of aluminium, rusty iron, brass, copper) and objects made from metal (including a piece of copper pipe, several bar, horseshoe and disc magnets, nails and large shiny ball bearings). The children were given these pieces of metal and metal objects to inspect, and were then invited to ask questions.

A further 124 questions about 'metals' were obtained from children in three S.3 classes in the course of investigating the feasibility of an alternative teaching approach (Biddulph and McMinn, 1983). In one of these classes 18 questions were obtained by the researcher from the children during individual interviews prior to their teacher taking them for a series of lessons on the topic. During the first lesson the teacher himself obtained a further 31 questions. The stimuli in the interviews were the instances and non-instances of objects made of metal already referred to. In the class situation the teacher told the children that he would show them some things and later he would ask them if they had any questions about 'metals'. He used an interview-about-instances technique to show the children in their class group a number of metal and non-metal objects (including a paper clip, an aluminium milk bottle top, a piece of venetion blind, a length of plastic-coated copper wire, a tuning fork, a painted book-case bracket, a polished piston from a tractor motor) and invited the children to suggest whether each item should be put in the group labelled metal objects or the group labelled non-metal objects.

In the other two classes the children's questions were obtained in the course of lessons on 'metals' taken by the researcher. In both cases the children were told that they would be shown some metal objects and that

they would then be asked if they had any questions about 'metals'. The stimuli were again common objects but on these occasions they were all made of various metals. They included a small piece of copper pipe, a 2¢ coin, some aluminium foil, an aluminium milk bottle top, a silver spoon, a gold ring, a stainless steel bowl, a brass key, a steelo polypad, a lead sinker, a rusty nail, a chromium-plated teapot and a piece of bicycle brake cable. The stimuli were presented during the first lesson with both classes and the children were invited to offer any comments they might have about the object shown them before they were asked for their questions. One class responded with 15 questions - and asked another 25 questions during discussion in a later lesson - while the other generated 35 questions.